

Simulated WAve Visualizer (SWAV)

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LONG-TERM GOALS

The Simulated WAve Visualizer (SWAV) program will provide mission planners a valuable tool for visualizing near shore environments that will provide real-time actionable information that will influence the implementation of missions. The SWAV is a software program that will be deployed on ships so that naval personnel will be able to ‘see’ first hand the environment to which they are going to be deployed. Further, SWAV will be a powerful graphical training aid to educate novice seamen on the dynamics and dangers of the littoral environment. The realistic imagery produced by SWAV conveys a multitude of information that cannot be gained through numeric or simple sea state metrics.

OBJECTIVES

Scientific:

Useful Approximations in Wave Visualization – While the field of oceanographic hydrodynamics is quite mature, the use of analytical and computational approaches developed in that area for the development of realistic ocean surfaces has been largely studied only in the movie and video game industries. A key objective of the SWAV program is to establish an analytical approach that provides physically realistic ocean scenes with a minimum of computer resources to provide a gateway to a real-time ocean visualization tool.

Optical Properties of the Ocean Surface – Optical measurements of the ocean surface and sub-surface are commonplace. A key objective of the SWAV program is to connect meteorological conditions with sea surface optical properties to develop an analytical link between the instantaneous environment and the light transmission and reflection properties of the ocean surface.

Technological:

Procedural Ocean Simulation Software – The movie and video game industries have created strikingly realistic ocean scenes. However, due generally to economic realities, these scenes have required extensive interaction between artists and analysts that is extremely labor intensive. A key objective of the SWAV program is to apply the methodology developed in these sectors in a way that allows automated generation of physically realistic sea surfaces from real meteorological and environmental (met-e) data.

Applicability Graphical Processing Hardware – The power of commercially available graphical processor units (GPU) and multi-core processors has increased dramatically over the last decade.

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However, the wide varieties of hardware approaches and architectures make their selection and implementation complex. A key objective of the SWAV program is to establish a hardware architecture capable of inexpensively rendering physically realistic sea surface animations in real time based on current met-e input data.

APPROACH

The technical approach pursued in the SWAV program is to apply successful visualization techniques demonstrated in the movie and video game industry in three distinct wave regimes: 1) open water waves, 2) shore approach waves, and 3) beach waves. In each regime the parameters necessary to create the scene is built into a procedural software tool with met-e data as inputs. Then the boundary conditions necessary to seamlessly fuse these wave regions are calculated in an overall software architecture allowing real-time visualization of a complete wave environment from beach front breakers to open water fully developed seas and swell. The final SWAV tool is envisioned as a stand-alone visualization environment running on a commercially available GPU/multi-core graphical workstation.

To help realize the SWAV technology, several key individuals and institutions outside of TALLC have contributed:

- Len White (Templeman Automation, LLC) – Principal Investigator and director of visual effects and simulation for Templeman Automation. Mr. White has spearheaded the SWAV development effort.
- Jerry Tessendorf (Rhythm & Hues Studios) – An acknowledged expert of ocean scene rendering in the movie and video game industry. Mr. Tessendorf’s lecture series presented at the annual SIGGRAPH conference forms the basis of most every Hollywood studio’s ocean rendering tool kit. He has been involved in the SWAV program since the start of Phase I and provided invaluable insight into current approaches and software assistance.
- Jeff Hanson (USGS/FRF) – Director of the Duck, NC Field Research Facility (FRF) and an expert in wave modeling and wave tracking software. Dr. Hanson has helped guide the collection and evaluation of met-e, photographic, and video data used for baselining the SWAV imagery and is an enthusiastic supporter of follow-on applications.
- Tom Kluyskens (Sony Imageworks) – Nearly concurrently with the start of the SWAN program, Sony’s “Surf’s Up” feature film was released. “Surf’s Up” pushed the state-of-the-art in realistic and proceduralized generation of breaking wave imagery. Mr. Kluyskens was a key developer in those wave models and has contributed guidance on beach wave approaches and software implementation.
- Robert Dalrymple (Johns Hopkins University) – Dr. Dalrymple is an internationally-known researcher in computational fluid dynamics and oceanographic simulation. His expertise in the “Smoothed Particle Hydrodynamics” (SPH) approach is especially applicable to the procedural framework of the SWAV program. He has provided hydrodynamic insight and initial consulting in the Phase I SWAV program.

WORK COMPLETED

Several tasks were completed for the Phase I effort. SideFX's Houdini software was chosen as the software development environment. After the kickoff meeting, the FRF at Duck North Carolina was chosen as a case study. With help from FRF personnel, real world wave data from near the FRF pier was analyzed and compared with SWAN output. Further bathymetric data was compiled. Once all the real and modeled data was collected a custom Houdini operator was created to take SWAN data as input and generate realistic open ocean wave images using an FFT method. Realistic sea surfaces were created and various lighting and shading effects were evaluated.

To model the shore approach zone, iWave, a boussinesq-based software wave model produced by Phase I collaborator Jerry Tessendorf, was evaluated. The code was modified to accept arbitrary bathymetries and further work including integrating this code into Houdini via a custom operator node. This iWave variant is called sWave.

Initial work has been undertaken to model breaking waves. An initial wave model was created using the "wire deformer" technique. This technique uses a series of "control lines" to deform a 3-D grid in a similar way that one might use several strings to create a particular draping effect with a cloth. The wire deformer is one of several deforming and molding techniques that allows direct manipulation of polygon edges and vertexes. Similar geometric operations include extrusion and twisting.

Investigations continued toward generating animated wave profiles based on field data of real waves and established hydrodynamic models of breaking waves. Each wave function begins shortly before the profile becomes multi-valued and evolves in roughly 20 steps until the wave height is essentially exhausted. Profiles can include highly non-linear and turbulent behavior such as wave cap separation, geysers, and splash-up.

The second step of the approach is to establish cellular "wave particles" that propagate with approaching waves along the gridlines of the modeling space. Several hundred to thousands of such data markers could be used along the wave front to define the extent of a single breaking wave. Each "particle" in the software simulation is a place-holder for a series of data values associated with the instantaneous location of the wave front. In this way the initial speed, the local bathymetry, beach slope, wavelength, and other parameters for the wave are virtually "measured" as the particle propagates with the incoming wave. These particles spread evenly across the approaching wave front, and govern the evolution of the wave profiles. Depending on the instantaneous location, local water depth, and speed of the particle, the profile of the incoming wave is deformed to match each successive step in the evolving wave profile. For each profile step, the speed or other particle parameters can be modified instantaneously or algorithmically. To aid in the generation of these profiles smooth particle hydrodynamics (SPH) is being investigated. SPH brings additional physics-based realism to the profiles as well as the potential for simulating more turbulent effects such as spray and splashing.

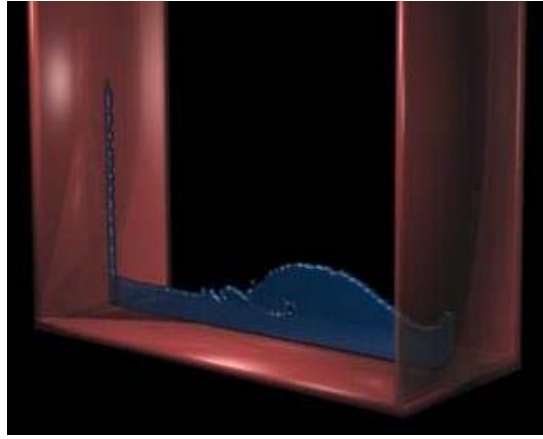


Figure 1. Johns Hopkins University smooth particle hydrodynamics simulation visualized by the Templeman Automation team using Houdini software

RESULTS

Three software modules have been created as a result of this program effort. The first module is the SWAV FFT Houdini operator. This node utilizes an FFT wave model to produce realistic images and animations of open ocean waves. The SWAV FFT node takes SWAN modeled or real world data as input. This is significant because it takes scientific data and presents it a way that is meaningful to the lay person. Three data sets from FRF 6 meter wave array sensor were used as input to test this module. The output from SWAV matched well with the images of the sea surface from those days.

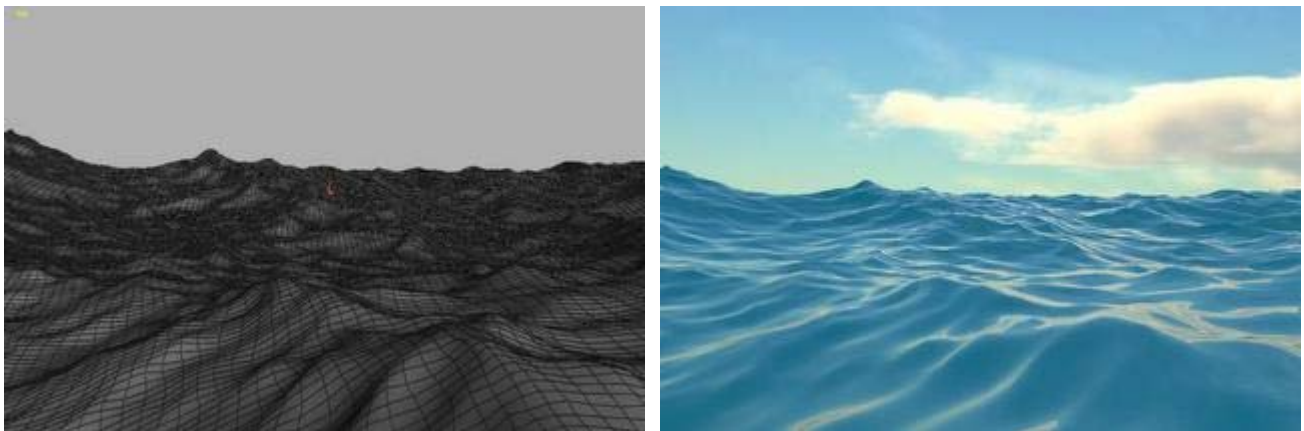


Figure 2. Images created using the SWAV FFT node. Image on the left is pre-rendered image derived from SWAN input. Right image is same scene rendered with realistic water optical properties.

Video was collected from a kayak at FRF. The scene collected by video was replicated as a computer generated scene using the SWAV FFT node. Based on the images acquired at the FRF the model of the Duck beach environment was refined with additional details. In some instances, colors and textures from the photography could be applied directly to Houdini model of the beach. The clear and

consistent sunlight allowed refinement of lighting and shader properties that are applicable to a wide range of scenes.



Figure 3. Two still images cut from movies of FRF pier. Left image is from a video capture from a boat. The right image is a single frame from a computer generated SWAV animation of the same scene.

As part of the scene generation for this test run, it became apparent in both the actual photography and the CG imagery that wave images and animations in the absence of visual cues such as the horizon, sky, beach, pier, people, or boats were significantly less convincing than those with at least one such cue.

The next software program created was sWave. This program calculates the ocean surface and takes into account arbitrary bathymetry and obstacles. Using this program we were able to visualize realistic water dynamics such as reflection, diffraction, rippling around obstacles and waves lining up with the beach front. This program is essential to connect the open ocean model to the near shore breaking wave model.

In order to model breaking waves a third program was created. This program, currently implemented as a Houdini operator, is called bWave. Using bWave, realistic animations of breaking waves were completed. The key features of this program are 1) that the wave field is no longer treated strictly as a ‘height field’ of displacements in only one direction, but rather as a deforming mesh that can appropriately fold over upon itself. And, 2) the dynamics of the breaking waves are governed procedurally by the inputted bathymetry. Thus this program serves as a procedural foundation in which any arbitrary beach may be input and the waves will automatically break according to the particularities of that bathymetry of the beach (e.g. sand bars).

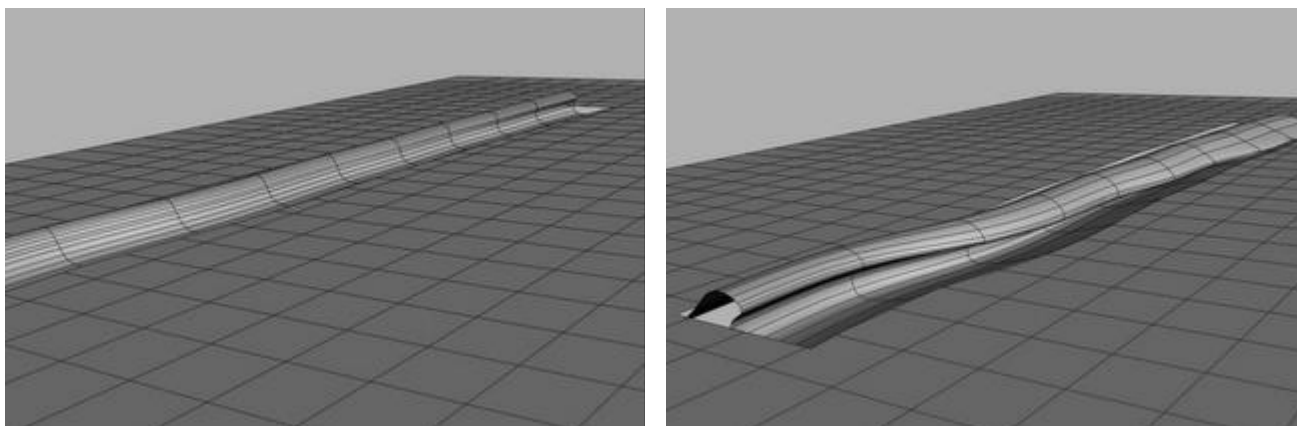


Figure 4. *Still frames from bWave software animation. Image on the left shows wave setup. Image on the right shows same wave breaking. Note that the wave is breaking at different points along the long axis. The wave is automatically breaking according to the underlying bathymetry, which in this case is non-uniform along the long axis.*

IMPACT/APPLICATIONS

The SWAV program will provide a valuable mission planning and training aid tool for the Navy. The SWAV program will provide actionable information to mission planners that will enable them to tailor the mission parameters and strategy in concert with the ever evolving sea environment. The mission planner will be able to visualize risks to personnel and equipment that may not be evident in numeric models and thus be able to modify the mission to account for such perceived risks. Further, Templeman Automation LLC (TALLC) is involved in the development of novel underwater sedimentology sensors for coral reef studies in collaboration with USGS, and the development of a new kind of towed-body pressure-mine influence sweeping system for the US Navy. In both these systems, the physical and graphical models of wave action gained by the ongoing SWAV program has improved designs and reduced technical risk. In addition, growth areas at TALLC, including ocean energy and underwater optics, will benefit from the advances made in the current effort. The SWAV program provides a general visualization tool that has broad applicability to numerous oceanographic efforts.

TRANSITIONS

The Virtual Surf Camera (VSC) is the first application of the SWAV program. The Army Corps of Engineers field research facility at Duck plan on setting up VSC to cover an area of ocean currently monitored by their '6 meter array' and modeled using SWAN. The VSC images will be web cast concurrently with the data from the array and numeric and plotted data from SWAN. This effort is slated to be completed over FY08. Duck has offered labor and expertise to aid in the setup, troubleshooting and maintenance of this system. This is the first step to produce a commercial VSC that will find applicability in the surf forecast market (e.g. surfline.com) as well as use in environments and locations for beach-based web cameras where installation is problematic or not available.